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1. Your reference	ID 99-033/KL/ad	9922002.2
2. Patent application number *(The Patent Office will fill in this part)*	9922002.2	20 AUG 1999
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Smith Group Limited Surrey Research Park Guildford Surrey GU2 5YP	THE PATENT OFFICE L 20 AUG 1999 LONDON
Patents ADP number *(if you know it)*	7761604001	
If the applicant is a corporate body, give the country/state of its incorporation	England	
4. Title of the invention	DEMODULATOR	
5. Name of your agent *(if you have one)*	QED I.P. Services Limited	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Dawley Road Hayes Middlesex UB3 1HH England	
Patents ADP number *(if you know it)*		

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7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	Yes

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Continuation sheets of this form	
Description	8
Claim*(s)*	–
Abstract	–
Drawing*(s)*	1 +1

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Priority documents	–
Translations of priority documents	–
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	–
Request for preliminary examination and search *(Patents Form 9/77)*	–
Request for substantive examination *(Patents Form 10/77)*	–
Any other documents *(please specify)*	–

11. I/We request the grant of a patent on the basis of this application.

Signature Date 19.8.99

QED I.P. SERVICES LIMITED

12. Name and daytime telephone number of person to contact in the United Kingdom — Keith Leaman, 0181 848 6633

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This invention relates to the detection of carrier signals of Quadrature Amplitude Modulated (QAM) signals and Phase-Shift Keyed (PSK) signals and domodulators for demodulating QAM and PSK signals.

In QAM, two carrier signals in phase quadrature are amplitude modulated by a modulating signal and combined for transmission. Each transmitted symbol can thus have a relatively large number of phase and amplitude states, which are generally illustrated as signal points in a signal point "constellation" in a phase plane diagram. The binary components (I and Q) of the two carrier signals are plotted with the values of I along a horizontal axis and the values of Q along an orthogonal vertical axis. PSK is a restricted set of QAM signals, with constellation points on one or more rings in the phase plane diagram.

Phase shift errors cause the constellation points to rotate through an angle φ from the position where the two carriers are in phase quadrature, and it is customary to use correction algorithms to cancel out the rotation and lock the signal.

Conventional QAM demodulators extract from the combined modulated signal, two binary components I and Q modulated in phase quadrature. The combined modulated signal is generally expressed by $I \cos(2\pi ft) + Q \sin(2\pi ft)$. An oscillator is used to generate two signals in phase quadrature at a frequency close to the anticipated carrier frequency, f, but in phase. The oscillator signals are mixed with the modulated signal to give two channels, I and Q, and an ac component of a frequency twice that of the respective carrier. The ac component is removed leaving two binary signals I and Q.

In order to demodulate the modulated QAM signal, the carrier phase and frequency needs to be accurately determined and extracted from the modulated signal.

All carrier frequency extraction algorithms exploit non-linearity of the modulated signal. Standard techniques are discussed in Webb and Hanzo, "Modern Quadrature Amplitude Modulation" IEEE Press and Pentech Press, 1994. The main techniques for carrier recovery are: -

(a) times-n carrier recovery – where the signal is raised to the power of n, and the signal locked to n-times the carrier frequency; and

(b) decision directed carrier recovery – where a decision is made as to the nearest constellation point and the error used to modify the frequency.

Decision-directed feedback can only be used for small frequency errors, (much less than bandwidth/n), as the symbols may be incorrectly determined for larger errors. For the same reason the carrier may not be determined if the signal has poor equalisation.

Times-n recovery does not require the signals to be equalised as well as that for decision-directed recovery. Furthermore, times-n recovery has a much wider capture frequency. However, previously known times-n recovery techniques cannot be applied to arbitrary constellations, and do not make use of the symmetry of constellation points.

The present invention use the time-n technique but can be applied to arbitrary constellations and makes better use of the symmetry in the constellation information than was possible with previously known times-n recovery techniques. The present invention does not require well-equalised signals and has a wide capture frequency. The technique of the present invention also provides carrier phase detection as well as frequency detection.

In one aspect of the present invention, there is provided a method of detecting a carrier signal of a QAM signal comprising the steps of: -

(a) sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal,

(b) down-converting the components I and Q to a baseband frequency,

(c) scaling the components I and Q so that the I and Q magnitudes are those expected for the constellation,

(d) deriving the average times-n phase for the constellation by calculating the complex vector Φ where Φ is given by: -

$$\Phi(r) = \frac{\sum_p w(r - r_p)\exp(in\phi_p)}{\sum_p w(r - r_p)}$$

where p is an index running over symbols in the constellation;

r_p	is the radius to the constellation point;
φ_p	is the phase of the constellation point;
n	is the constellation symmetry (For example 4 for four-fold symmetry, e.g., for 16QAM); and,
w	is a smoothing function

(e) determining the phase of the carrier signal, and

(f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation :-

$$F(\omega)=\sum_d W_d \Phi^*(r_d)\exp(in\phi_p - i\omega d)$$

where

d	is an index running over data samples;
r_d	is the amplitude of a data sample;
φ_p	is the phase of a data sample;
W_d	is a (real positive) windowing function (e.g. Hanning);
$\grave{U}$	is angular frequency = $2nf$, where f is the real frequency.

In a further aspect of the present invention, there is provided a method of demodulating a QAM signal comprising the steps of :-

sampling the digital-in-phase binary components I and Q of an incoming QAM modulated signal,

(b) down-converting the components I and Q to a baseband frequency,

(c) scaling the components I and Q so that the I and Q magnitudes are those expected for the constellation,

(d) deriving the average times-n phase for the constellation by calculating the complex vector Φ where Φ is given by:-

$$\Phi(r)=\frac{\sum_p w(r-r_p)\exp(in\phi_p)}{\sum_p w(r-r_p)}$$

where

p	is an index running over symbols in the constellation;
r_p	is the radius to the constellation point;
φ_p	is the phase of the constellation point;

n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for 16QAM);

w is a smoothing function

(e) determining the phase of the carrier signal, and

(f) determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation :-

$$F(\omega) = \sum_d W_d \Phi^*(r_d) \exp(in\phi_p - i\omega d)$$

where d is an index running over data samples;

r_d is the amplitude of a data sample;

φ_p is the phase of a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

Ù is angular frequency = $2nf$, where f is the real frequency; and,

(g) subtracting the detected carrier signal from the incoming QAM signal to derive the modulating signal in the incoming QAM signal.

In another aspect of the present invention there is provided a carrier signal detector for detecting the phase and frequency of a carrier signal in Quadrature Amplitude Modulated signals, said detector comprising :-

(a) sampling means for sampling the digital-in-phase components I and Q of an incoming QAM modulated signal,

(b) frequency conversion means for down-converting the components I and Q to a baseband frequency,

(c) phase angle measurement means for deriving the average times-n phase operable to calculate the complex vector Φ where Φ is given by:-

$$\Phi(r) = \frac{\sum_p \iint \left| w(r\cos\phi - I_p, r\sin\phi - Q_p) \right| \exp(in\phi) r d\phi}{\sum_p \iint \left| w(r\cos\phi - I_p, r\sin\phi - Q_p) \right| r d\phi}$$

where p is an index running over symbols in the constellation;

r_p is the radius to the constellation point;

φ_p is the phase of the constellation point;

n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for 16QAM);

w is a smoothing function;

(d) carrier phase determination means for determining the phase of the carrier signal in the incoming QAM signal, and

(e) frequency determining means for determining the frequency of the carrier signal in the incoming QAM signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation:-

$$F(\omega) = \sum_d W_d \Phi^*(r_d) \exp(in\phi_d - i\omega d)$$

where d is an index running over data samples;

r_d is the amplitude of a data sample;

φ_d is the phase a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ù is angular frequency = 2nf, where f is the real frequency.

In another aspect of the present invention there is provided a demodulator for demodulating Quadrature Amplitude Modulated signals, said demodulator comprising :-

(a) sampling means for sampling the digital-in-phase components I and Q of an incoming QAM modulated signal,

(b) frequency conversion means for down-converting the components I and Q to a baseband frequency,

(c) phase angle measurement means for deriving the average times-n phase operable to calculate the complex vector Φ where Φ is given by:-

$$\Phi(r) = \frac{\sum_p \int \left| w(r\cos\phi - I_p, r\sin\phi - Q_p) \right| \exp(in\phi) r d\phi}{\sum_p \int \left| w(r\cos\phi - I_p, r\sin\phi - Q_p) \right| r d\phi}$$

where p is an index running over symbols in the constellation;

r_p is the radius to the constellation point;

φ_p is the phase of the constellation point;

n is the constellation symmetry (for example, 4 for four-fold symmetry, e.g., for 16QAM);

w is a smoothing function;

(d) carrier phase determination means for determining the phase of the carrier signal,;

(e) frequency determining means for determining the frequency of the carrier signal by calculating the maximum amplitude component in the complex Fourier transform F of data from the samples according to the following equation:-

$$F(\omega) = \sum_{d} W_d \Phi^*(r_d) \exp(in\phi_d - i\omega d)$$

where d is an index running over data samples;

r_d is the amplitude of a data sample;

φ_d is the phase a data sample;

W_d is a (real positive) windowing function (e.g. Hanning);

ù is angular frequency = 2*nf*, where *f* is the real frequency; and

(f) carrier subtraction means for subtracting the detected carrier signal from the incoming QAM signal.

Where there are many constellation points with widely differing phases, the magnitude of Φ is small, otherwise the magnitude is large, and hence those constellation points that provide little information on the carrier frequency will be weighted down.

The phase of Φ is the average times-n phase of the points with that radius. When this is subtracted from the phase of the sample data, this improves the recovery algorithm by removing phase errors for samples with different amplitudes.

Preferably the weighting function (w) is chosen to have a spread comparable to that expected in the data, and zero beyond that. The weighting function may be Gaussian, triangular, or rectangular or other.

The present invention will now be described, by way of an example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of a demodulator constructed in accordance with the present invention.

Referring to Figure 1 the demodulator (10) comprises basically two main components, namely a high performance programmable digital signal processor (11) built around a number of fairly conventional hardware signal processing integrated circuits, and a high power computer 12 comprising two power PC's 13, 14. One of the PC's (13) serves as the controller and the other handles the input and output interfaces.

These two components 11, 12, are coupled, and large RAM buffers are provided to collect snapshots of data which are read by the PC's 13, 14. The PC's 13, 14 are able to upload the required processing parameters to the digital signal-processor 11, and also provide a remote connection facility 15, either via a Wide Area Network (WAN) or serial port. There is a variety of conventional options available for this interface.

Remote access allows full interactive control of the demodulator 10, including retrieval of snapshot data, uploading digital signal processing data, and uploading of the PC's software.

The digital signal processor (11) provides a generic capability for equalisation filtering and demodulation. Within the underlying constraints of the hardware, such as filter lengths and sampling rates, any signal format can be handled. Standard modulation schemes such as 16, 32, 64, 128, 256, 512, 1024 QAM and BPSK, QPSK, S-QPSK, 8-PSK can be handled by the demodulator.

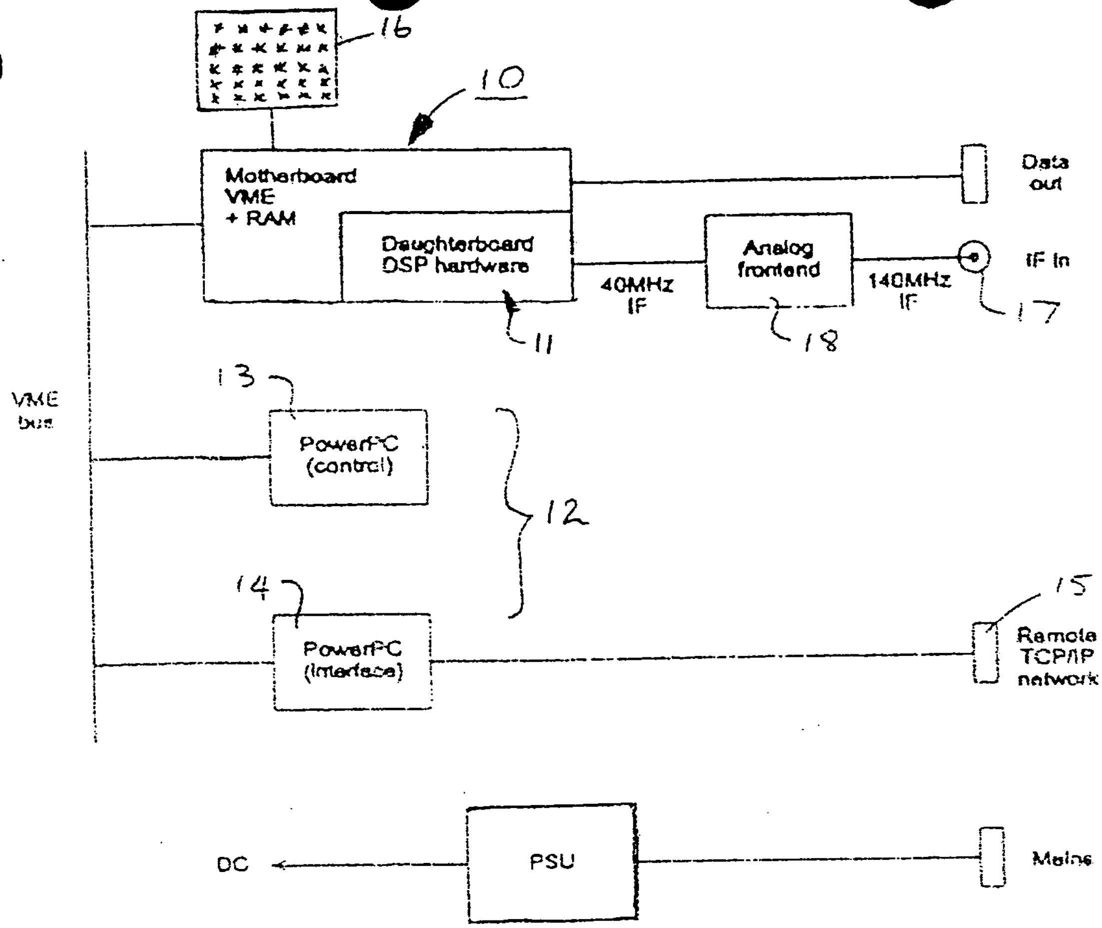
The equalisation method used is a 64 complex tap FIR filter operating on samples at twice the symbol rate.

Mounting of collection operations can be very time consuming. However the present demodulator can be used against unknown signal types and can be programmed in the field to cope with almost any signal type.

The demodulator is provided with a screen 16 on which the constellation points of a phase-plane map can be displayed.

In use of the demodulator 10, the incoming modulated QAM signal (at an intermediate frequency, typically of 140MHz, with an input impedance of 50 ohms), is supplied at the input 17 to an analogue front-end unit 18. The front-end unit 18 converts the 140MHz analogue signal to an analogue signal centred approximately at 40MHz. The 40MHz analogue signal is digitised at a sample rate of 160MHz, and then mixed down to baseband with I and Q channels sampled at 80MHz.

Data are captured from the digitised signal at this point, to identify the approximate symbol rate. The signal is then resampled at twice the symbol clock rate. Data are captured after resampling, and the symbol clock rate is then accurately identified and tracked.
The digitised signal is equalised and decimated by a factor of two to give digital I and Q signals at the symbol rate. These I and Q data are captured and form the input to the carrier recovery which is performed according to the present invention. The detected carrier frequency and phase are used to control a digital mixer, the output of which is passed to a look-up table that translates the I and Q values to the final symbol values. The detected carrier signal is subsequently subtracted from the incoming modulated signal in order to derive the modulating signal of the incoming signal.



System block diagram